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FROM THIS ROOM

THE VACUUM EVAPORATION OF SOME METALS FOR FABRY PEROT INTERFEROMETER MIRRORS

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THE VACUUM EVAPORATION OF SOME METALS FOR FABRY PEROT INTERFEROMETER MIRRORS

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I. INTRODUCTION

The investigation of spectra has revealed that the frequencies of the light emitted by atoms is given by the difference of energy levels. The theory of the emission and absorption of radiation is intimately associated with minute differences between the values of the levels, that is to say, apparently simple levels are split into multiples, as in the Zeeman effect, the Stark effect, the fine structure of Hydrogen and ionized Helium and the hyperfine structure of spectral lines. The detection and measurement of these minute energy differences requires great resolving power and high dispersion in the dispersing instrument. For example the mercury green line when excited under suitable conditions possesses hyperfine structure, the detection of which necessitates a resolving power of 800,000. Resolving power is defined as $\lambda / \delta\lambda$ where λ is the wavelength and $\delta\lambda$ the difference in wavelength between two lines that are just separated.

By using concave gratings of long focal length and with a large total number of lines it is possible to increase dispersion and resolution and resolution respectively. Such apparatus is very unwieldy and since the limit of length of the ruled surface of gratings with present ruling methods is about

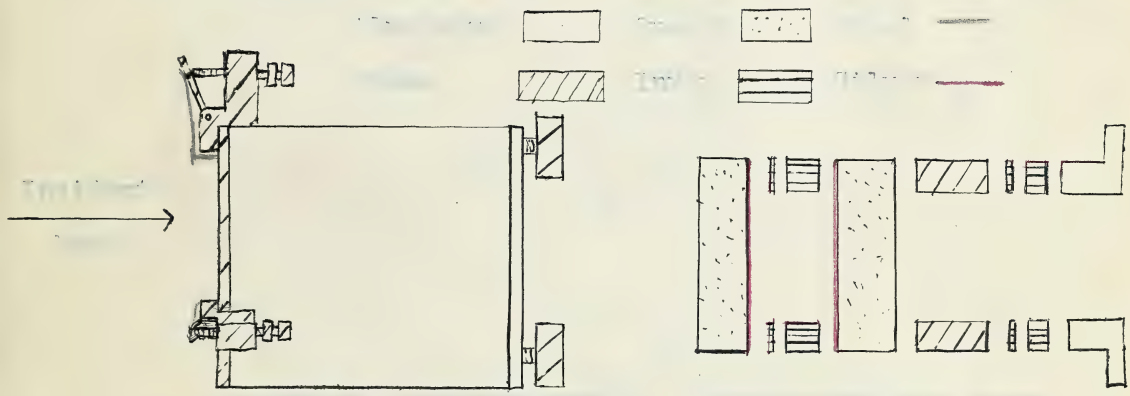
six inches, the theoretical limit to the resolving power is about 300,000 at 5,000A, in the maximum possible order, with a practical limit of about half this.

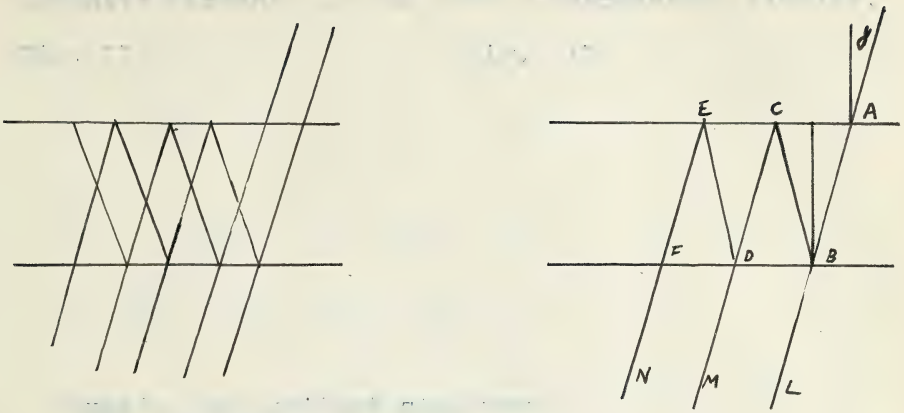
The use of transparent echelon gratings concentrating the light into the high orders increases resolution, but at the expense of ambiguity of interpretation due to excessive overlapping of orders. A pile of thirty, one-centimeter plates would have a resolving power of about 600,000 at 5000A.

The Lummer Gehrcke plate has a high resolving power, about 600,000 at 5000A for a six inch plate and proportionately greater for longer plates.

However it is costly, and has to be duplicated in various thicknesses to prevent ambiguity of interpretation.

The Fabry Perot interferometer has its resolving power under control by the use of invar separators of different thicknesses, the resolution being proportional to the thickness, and possesses the great advantage of being unaffected by temperature variations. One grave disadvantage is that the dispersion is constant. The interference pattern is a series of concentric rings. As the separation of the reflecting surfaces is increased to increase resolution, the ring diameters of the interference pattern decrease. Since dispersion is constant, the breadth of the ring,




E
C
A
F
D
B
N
M
L

$$\sum_{m=0}^{\infty}$$

IT [illegible] THE FABRY-PEROT INTERFEROMETER

RESOLVING POWER. Two lines are said to be resolved when the intensity of one is a maximum, and the other is at its first zero minimum at the same point. The intensity is defined as the square of the amplitude.

In the case of the Fabry Perot interferometer there are no zero minima in the interference pattern and some other criterion of resolution is necessary. The definition of resolution to be used is that two lines are resolved if the point at which one is a maximum corresponds with the point at which the [illegible] has half its maximum amplitude; that is one quarter its maximum intensity. This definition is quite arbitrary but has been used elsewhere. For a maximum at the center $\cos 2\pi d/\lambda = 1$.

$\sqrt{I_\lambda}$ is proportional to the amplitude of

$$\frac{\sin 2\pi t/\Gamma - r \sin 2\pi t/\Gamma}{1 - r}$$

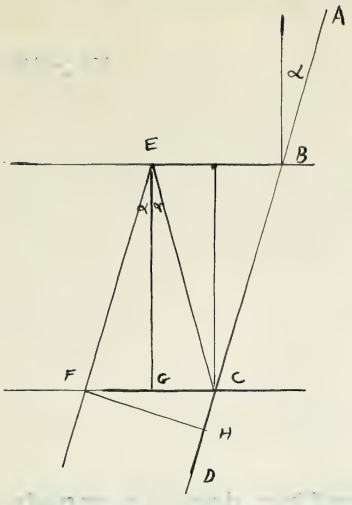
$$\therefore \sqrt{I_\lambda} = \frac{1 - r}{(1 - r)} = \frac{1}{1 - r}$$

where J is a constant of proportionality, and I_λ the intensity for wavelength λ.

Suppose the wavelength $\lambda + \delta\lambda$ is just resolved, the displacement at the center will be:-

$$Y = \frac{\sin 2\pi t/\Gamma - r \sin 2\pi(t/\Gamma - 2d/(\lambda + \delta\lambda))}{1 + \quad - \quad \pi \quad \lambda + \delta\lambda}$$

$$\frac{\gamma_1 \gamma_2 \cos\alpha \cos\mu + \sin\alpha \sin\mu \sqrt{\gamma_1^2 + \gamma_2^2 - 1}}{\gamma_1^2 + \gamma_2^2 + 2\gamma_1\gamma_2 \cos\alpha \cos\mu}$$


A
E
B
F
G
C
H
D

n and r^2 exhibit a linear correspondence. Since successive rings in the interference pattern are produced by decreasing n in unit steps, the squares of the radii of adjacent rings will differ by a constant. If a line of wave length λ has a satellite at $\lambda + \delta\lambda$, $\delta\lambda$ may be calculated from the Fabry Perot interference pattern by means of the expression $Cd - Ar^2d = n\lambda$.

Let n be the difference between successive n's; C the count that the squares of the radii of rings due to the satellite are less than the squares of the radii of rings of the same order, due to the main line. It must be remembered that there is an uncertainty of $\pm$ n in C where n is any integer; owing to the uncertainty as to whether the ring due to a satellite and the adjacent ring due to the main line are of the same order or not. If $\delta\lambda$ is small n = 0; while if n is not zero it can easily be evaluated by checking with readings with a different value of d, the separation. In any case calculations can be carried to the point where the final interpretation has to be made on the assumption n = 0, without introducing any errors.

Substituting corresponding values of λ and r in

$$n\lambda = Cd - Ar^2$$

$$n(\lambda+\delta\lambda) = Cd - A(r \mp \quad)^2$$

Subtracting $n\,\delta\lambda = A\,$

Substituting corresponding values

$$n\lambda = D - A(r^2 + B)^2$$

gives $(n-1)\lambda = D - A(r^2 + B)^2$

$$\lambda$$

$$\lambda, \lambda_3$$

But $\text{tan}\, \theta = \alpha$ θ is small compared

to a first approximation $n\lambda = D$.

his gives $\delta\lambda = \frac{}{}\lambda$

In terms of wave number, $\nu = 1/\lambda$: $\delta\nu = \lambda, \lambda_3$

$$\delta\nu = \frac{}{} \frac{}{} \qquad \nu$$

III THE PREPARATION OF METALLIC FILMS BY EVAPORATION IN HIGH VACUUM

Any substance exerts vapour pressure. This pressure will reach an appreciable value before the normal boiling point is reached. If it is placed in a chamber where the pressure is less than the vapour pressure it will evaporate freely, the rate depending on the temperature. It is found that a stream of molecules will condense in the form of a smooth layer on a surface if the molecules do not collide with other molecules appreciably and the stream density is great enough*.

Thus metal evaporating in a vacuum from a filament, will condense to a mirror on a suitable receiving surface if the filament temperature is suitable and if the mean free path of the residual gas is less than the distance from the filament to the surface.

The apparatus used was similar to that described by Pitchl*. It consisted of a horizontal brass cylinder, to a hole in the top of which was connected a mercury diffusion pump, and to perforations in the sides two terminals for the heating circuit. A glass tube carrying two electrodes was also connected in order to test the degree of vacuum. All joints were made air tight with sealing wax. (Vacuum wax

* Cockcroft, Proc.Roy.Soc., 114, 293, 1926.

Pitschl, Z.S.f.Phys., 60, 590, 1931.

was used originally but heat generated by the larger gauge filaments caused leaks.) The ends were closed with brass plates, one soldered in place and the other held by eight studs and wing nuts, the contacting surfaces being machined and sealed with vacuum grease. Windows were placed opposite each other in the end plates for observing the extent of plating. [illegible] was placed a [illegible] filaments and adjustable holders for the discs to be coated. In all cases the tank was exhausted until the spark from a coil will jump an auxiliary gap of about one inch in preference to passing through the vacuum, corresponding to a pressure in the neighbourhood of .01 millimeter. As .01 mm. gives a mean free path for air of about $\frac{8}{100}$ cm., the exhaustion should be carried considerably beyond this point.

Through placing the discs to be coated at an equal distance from the filament it was hoped to produce exactly similar films on both sides, but the drops of molten metal instead of hanging vertically from the filament and evaporating uniformly in all directions would climb up the side of the wire and frequently cause lack of perfect uniformity of the films. For this reason the form of apparatus described by Cartwright and Strong* would have been preferable.

* Cartwright & Strong, Rev.Sci.Inst. 2, 199,1931.

III. THE EVAPORATION OF METALLIC FILMS IN VACUUM

Only metals were evaporated and they may be divided into two classes:

Those such as silver copper etc. that readily run into drops. Unless care is taken these will not wet to the filament. In order to minimize this the filament is formed as shown, fig.V, preventing the

agglomeration into large globules. With certain of the less adherent metals such as silver it is necessary to give new filaments a preheating to remove the smooth oxide coating.

Magnesium and aluminium form the second class. They have a thin oxide film always present, and owing to their low density often retain their form in the molten state. This results in poor thermal contact with the filament and leads to soot like deposits: apparently due to the high filament temperature necessary for evaporation.

The quartz discs were carefully cleaned before plating. The old films were washed off with concentrated nitric acid, rinsed with distilled water followed by 95% alcohol, absolute alcohol was then flowed over them and they were placed on edge to dry. When any deposit remained that did not dissolve in the nitric acid, the discs were swabbed with small

III PREPARATION OF METALLIC FILMS BY EVAPORATION IN HIGH VACUUM

pads of absorbent cotton that had been boiled for a long time in distilled water to remove dust. Care had to be taken to rub the quartz evenly all over, as any local treatment might destroy the perfection of the surface. In order to preserve the quartz, small glass discs were substituted except when the films were to be used in the interferometer.

With regard to choosing suitable metals, the optical properties of very thin films have been found to differ considerably from those of the massive metals.

If n = index of refraction,

k = coefficient of absorption

R = percent reflection for normal incidence

d, λ = thickness and wave length in the same units

I_x = intensity at the depth x

T = % transmission = I_d/I_o approximately.

$$I_x = I_o e^{-4\pi nkx/\lambda}, \qquad T = 100 e^{-4\pi nkd/\lambda},$$

$$R = 100 \frac{n^2(1+k^2)+1-2n}{n^2(1+k^2)+2n-1}$$

(This formula for R does not seem to give very good results)

In working with an interferometer, since high reflecting power is desirable, Transmission should be kept low. 8% transmission is sufficient to give a reasonably short exposure for photographing most lines. This

corresponds to a thickness [illegible] = 500A°, for silver, for light of wavelength 5000A. Standard tables[#] and Hurmann's figures[*] indicate that as the thickness of a metallic film is decreased, n and k remain constant until a certain thickness is reached, when a gradual change takes place until another point is reached after which n and k change sharply as the thickness is decreased. For silver the region of slight change for n and k is from a thickness of 500A to a thickness of 150A. These regions depend to a certain extent on the wavelength. The region of great change is below 150A.

It can be seen that the thicknesses of films used correspond to the region of slight change in n and k . Therefore the reflecting power of the films is indicated roughly by that of the massive metals, though small differences were to be expected. For this reason the metals to be plated were chosen by selecting those with high reflecting power in the massive state.

These included ;

Aluminum, silver, rhodium, copper, [illegible] and tin. A few trials were made with zinc but no results were obtained.

[illegible]

[illegible]

This metal forms a liquid alloy with tungsten. For this reason filaments of .05 cm. diameter are necessary to prevent breakage due to [illegible] is found best to take precautions if long heating is necessary as the whole tank will rise in temperature. Aluminium is most satisfactory when in wire form of about .45 mm. diameter, threaded through the bends of the filament. This was produced from 22 gauge Aluminium by dipping in [illegible] dilute acid. The filament was heated to a bright orange with a current of 13 - 15 amperes, giving a heavy coating in five to ten minutes. If the aluminium will not flow, and higher temperature is used, colored or soot like deposits will often result. A rise in thermal pressure may also be a contributing factor. Two explanations have been put forward, one that they are interference colors due to the interference between light from different layers[1-2], and the other that they are due to resonance at a surface consisting of [illegible] minute particles[3-4]. It is possible that both explanations may be true as the colors seem to be of two types: a system of colored rings similar to Newton's rings, and a general layer of more or less uniform

1. [illegible] J.O.S.A. 27, 100, 1937.
2. [illegible]ison, J.O.S.A. 23, 302, 1933.
3. [illegible], Proc. Roy. Soc. 110, 310, 1910.
4. [illegible]

exhibiting brilliant

the path of a strong beam of

surrounding the main re-

flected image, indicating a granular structure.

Colours also appeared less frequently for tin and

other metals.

PALLADIUM. Filaments of .025 and .030 cm. diameter were used and uniformly good films could be obtained except that occasionally the silver would drop off the filament. 28 gauge silver wire was beaten into ribbons which were cut lengthwise into two or three strips. These were wrapped around the tungsten wire about one half inch of 28 gauge wire being sufficient for a pair of mirrors spaced about 9cm. from the filament. Nitschl recommends treatment of the finished mirrors with aqua regia vapour or hydrogen peroxide vapour to increase strength and reflecting power. Aqua regia was found unsatisfactory as pin holes in the film could not be avoided, so that treatment was confined to hydrogen peroxide vapour.

CADMIUM. This is a very difficult metal to handle as to tungsten. Results were obtained

minutes. The formation

is evaporated from a tungsten .025cm. filament. A small portion is burned from each end of the [illegible] together into a [illegible]. The [illegible] at a bright orange heat.

It is necessary to reduce the surface area as much as possible to evaporate magnesium. Bare nichrome wire with the oxide coating scraped off was used as a coiled heater of .05cm. tungsten wire. [illegible] could not be depended upon and numerous [illegible]

[illegible] separated by asbestos. This [illegible]

photoelec-

45 degrees

normal incidence. Two photometers were used both being similar to that described by Beals*, except that the compensating beam was eliminated. The first one used a potassium cell which was unresponsive to the yellow region, and dry B batteries which did not seem to give a steady current, so that the first sets of readings only apply to the blue region of the spectrum and may be considerably in error. The second a microphotometer, used storage batteries exclusively and had a commercial photoelectric cell which seemed to be sensitive to a great spectral range. In both cases measurements were comparisons with a standard, a totally reflecting prism with reflecting power about 90% and second a polished steel mirror with a reflection in the neighborhood of 65% throughout the region.

If R_s is the reflecting power of the standard and that of the prepared surface, D_s the galvanometer reading for the reflected beam from the standard onto the photoelectric cell, D_x the reading for the beam reflected from the unknown, and D_0 the reading when the beam is interrupted; then $R_x = \frac{(D_x - D_0)}{(D_s - D_0)} R_s$

*Astr. Phys. Journ., 64, 105, 1926.

Also if D_s is the reading when the surface is placed in the path of the beam from the standard, then the transmission is $= T = \frac{D_s - D_o}{D - D_o}$

In the first case the source was a 50 c.p. automobile head lamp bulb, projected in a parallel beam by a lens and a circular aperture. There was a second aperture before the photoelectric cell and by causing the light to fall squarely on this and on the center of the reflecting surface fairly constant results were were obtained. Some attempt was made to obtain values for different spectral regions by the use of filters, but due to the limited range of the cell the results were questionable.

For the second case a mercury arc was used as source; run at 110 volts with 20 ohms in series, and gave a fairly constant illumination except for line voltage changes. It took about five minutes to reach a steady state, and after that could be used till the level in the center tube started to rise, when it would have to be restarted. The light from the arc passed through a small spectrometer, and after reflection from the mirror to be calibrated was focussed in the

[illegible]

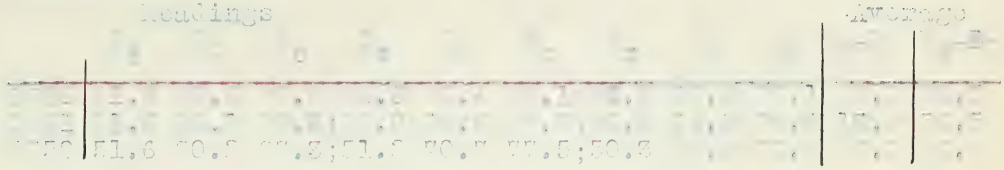
placed close to the slit and a strong converging lens placed between. The spectrometer prism was placed at minimum deviation and the mirror placed at a fixed point before the photometer slit. The mirror was then rotated till the violet line 4358 fell on the slit. The other lines were brought to the slit by rotating the prism. When the standard was to be substituted, in order to be sure that no conditions were changed, the prism was turned till the green line 5461 was bisected by the slit, the standard mirror substituted at the same point and turned about until the green line was again bisected. Measurements were made for three lines yellow 5760-5790, green 5461, violet 4358.

As an example the following readings were taken for a thin Aluminium film :-

Aluminium	Deflections	Average difference	Mean A.D.
5790	50.0; 50.4	50.1	49.5
5461	50.0; 50.4	50.2	49.7
[illegible]	[illegible]	[illegible]	[illegible]
Steel			
5790	51.1; 50.6	50.9	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
Aluminium			
5790	39.7; 39.1	39.9	
5461	47.6; 47.2	47.3	
4358	10.6; 10.5	10.7	

[illegible]

Transmission readings



[illegible]

[illegible] pedal. The deposition of silver mirrors for the interferometer was therefore confined to hydrogen peroxide vapour which seemed to improve reflection slightly. These films exhibited tints by transmitted light: pink, blue, etc. but this seemed to have no effect on the reflecting power. These readings were made with the first photometer: the following measurements were made with [illegible].

SILVER on quartz, after treatment with hydrogen peroxide.

$R_{5100} = 84.5\%$ $R_{5461} = 70.6\%$ $R_{4358} = 52.1\%$

$T_{5100} = 8\%$ $T_{5461} = 4\%$ $T_{4358} = 11\%$

[illegible]

[illegible]

[illegible]

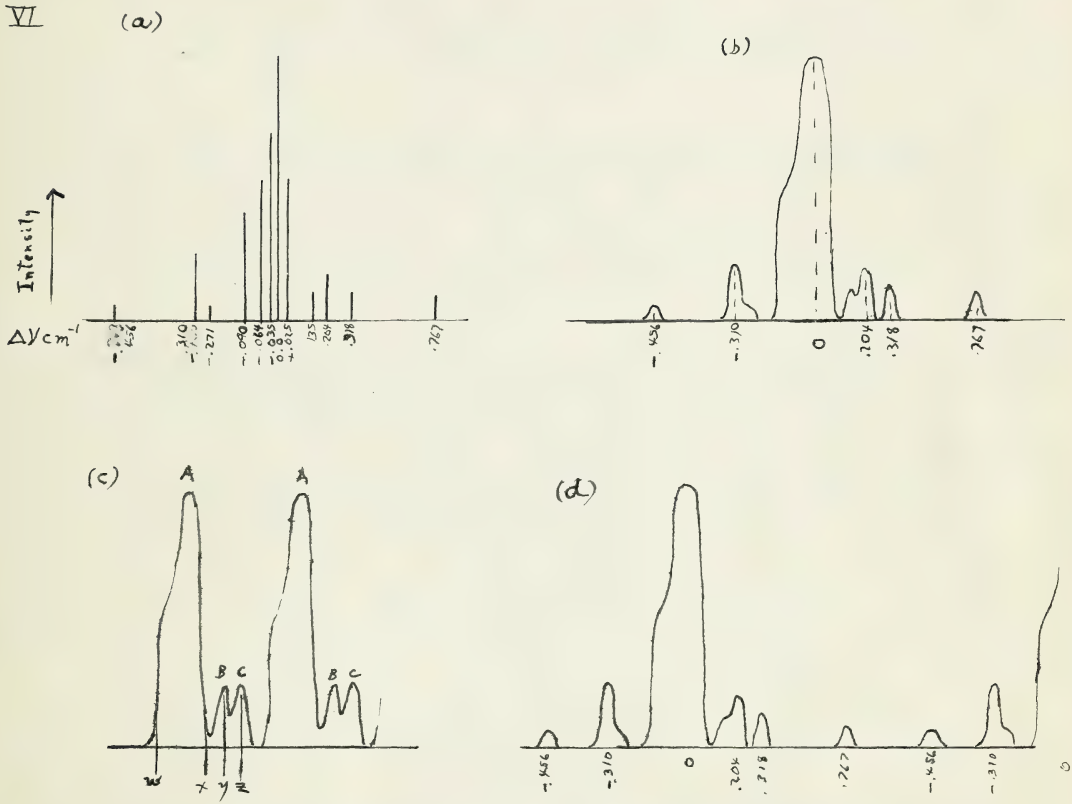
ALUMINIUM heated:

[illegible]

[illegible]

[illegible]

VI


(a)
Intensity
Δν cm⁻¹
-.456
-.310
-.271
-.090
-.084
-.035
0.015
.135
.204
.318
.767
(b)
-.456
-.310
0
.104
.318
.767
(c)
A
A
B C
B C
E
X
Y
N
(d)
-.456
-.310
0
.204
.318
.767
-.456
-.310

In pattern (c) considerable overlapping has taken place, the peak at O,(b), resting between .210 and .260; giving A (c) . B (c) consists of -.210 and.150. For 15cm. the separation per order is .216 ν so that -.210 lies at.156. Peak B is therefore between .106 and .136, probably about .130. Peak C is due to .004 alone. In (d) the spacing has increased eliminating overlapping.

The interferometer was assembled with the desired separations, and the springs adjusted until the rings diameters did not change on moving the eye. The rings were focussed on the slit of a Hilger constant deviation spectrograph and photographed. The plate was measured and the center of the pattern noted or calculated if off the slit. The radii of therings and their squares were calculated. This gave B and C directly (see pages 10 and 11), and thus $\delta\nu$. In the case of the silver films and the 15cm. separation the edges of the main line and the peaks of the two lines satellites appearing were measured. Calling these respectively w,x,y,z in order of increasing wave number, that is moving out from the center, w = 0 x =.136: y =.251; z =.312. z was identified with peak C inthe pattern (c), i.e. was .204 . This gave w =.-.108 x =.058 y =.133. These points when marked on the pattern (c) lie at the edges of the main line A and

.003 units of wave number of the

For the 3mm. separation the pattern was very faint. Ten repetitions of the pattern were recorded from several exposures. All faint successions of lines were recorded. It was then found that although there were many spurious lines, there was a grouping around .304, .3[illegible] etc. and it was therefore considered that thise lines wase resolved from the main line. This required a resolving power in the neighborhood of 150,000. This would correspond to 500,000 at 1cm. separation. In the case of the aluminium film that was tried the resolution was considerably less, apparently due to the lack of flatness of the film, it being of considerable thick-

I wish to take this [illegible] Stanley Smith, whose guidance and help made this work [illegible].

Also I wish to express my appreciation of the kindly interest taken by the ~~the~~ other members of the Physics department in this work; and to Mr. Beggs who supervised the construction of [illegible] the apparatus.

The chemistry department through Dr. Shipley kindly supplied the absolute alcohol [illegible].

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